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Quality Control of Meteorological Observations for the Fleet Numerical Oceanography Center Operational Atmospheric Database

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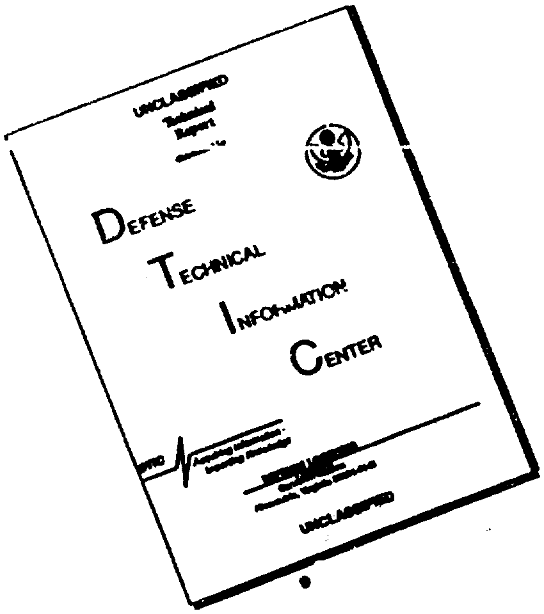

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Abstract

A new, operational meteorological database has been developed to provide quality controlled observations for the atmospheric analysis and prediction systems at Fleet Numerical Oceanography Center (FNOC). Quality control is a vital and necessary first step in atmospheric analysis and prediction since erroneous observations can adversely impact the accuracy of these environmental products. The meteorological observations are subjected to various validation- and error-checks prior to their storage in the operational atmospheric database. This technical note describes the quality control procedures, database structure and data formats used for the operational atmospheric database. It also discusses the specific details pertaining to the local implementation of the quality control system. These include: the treatment of *multiple, non-identical reports from the same station*; errors introduced by data processing; and the subjective quality control of marine observations. The same quality control procedures and data formats were used by the Naval Postgraduate School for some of the observations gathered during the Tropical Cyclone Motion experiment (TCM-90).

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Quality Control of Meteorological Observations for the FNOC Operational Atmospheric Database

1 Introduction

The Navy's current operational atmospheric database (ADPFNOC) was originally developed to provide quality controlled observations in a format acceptable for the Navy Operational Global Atmospheric Prediction System (NOGAPS)(Hogan et al. 1991). The database and quality control procedures were specifically developed for use by the multivariate optimum interpolation analyses (MVOI). The MVOI is the operational analysis used by the global model (NOGAPS), and the regional and stratospheric analyses at Fleet Numerical Oceanography Center (FNOC). Quality flags for the observations within a report are determined by quality checks made during the objective and analysis QC. However, only the NOGAPS MVOI analysis is allowed to write the analysis quality flags back into the database. After the NOGAPS MVOI has written the quality flags to the operational atmospheric database, the quality checked observations are transferred to a database on the front end computer for use by researchers and various applications programs.

The quality control (QC) of meteorological observations for the operational atmospheric database consists of four main components. These four components are pre-analysis objective quality checks, checks within the analysis for consistency against the background and neighboring observations, subjective evaluation of marine observations, and finally, the determination and correction of observational biases such as the radiative errors of radiosondes. In order to provide integrated quality control, the development and implementation of these four components must be coordinated. Ideally, no final QC decision would be made until all validation checks had been made. Then, the results of each test would be examined and a final decision made. This is the basic premise of the Complex Quality Control (CQC) as described by Gandin (1988). The development of the QC procedures discussed in this paper was coordinated, but quality decisions are made during each individual step.

This report describes in detail the pre-analysis objective QC. The subsequent checks against the analysis background and for consistency with surrounding observations made in the analysis are discussed by Goerss and Phoebus (1991). This technical note also discusses the elements of the system, such as data preprocessing and the structure of the database, that are unique to its operational implementation at FNOC. All of the details discussed here pertain to unclassified observations only. Appendices A and B contain the tables for the formats for the observations in the operational atmospheric database.

2 Data Processing, Formats and Database Structure

The global environmental observations are transmitted across the Global Telecommunications System (GTS) to users worldwide. The reports are retrieved from the GTS at Carswell Air Force Base, reformatted and relayed to FNOC by way of the Automated Weather Network (AWN). Additional observations from the Global Weather Intercept Program are transmitted from Carswell Air Force Base on the AWN. The National Meteorological Center (NMC) also retrieves the global observation set from the GTS and transmits them to FNOC via a direct link between the two centers. The NMC–FNOC data link provides a backup should the AWN from Carswell Air Force Base be unavailable. Satellite temperature retrievals are transmitted directly from NMC/NESDIS (National Environmental Satellite, Data, and Information Service) to FNOC . The raw observations are decoded and stored in packed-bit format in the FNOC operational files ADPFILE and SATFILE using the random access file manager, ZRANDIO. Each observation type is associated with a record name as shown in Table 1. The same record names are maintained for the quality checked data with one exception. The record name S0X is unique to the quality control processing and refers to the entire integrated radiosonde observation. The integrated sounding is made up of the lower (S0M) and upper (S0U) mandatory levels, and the lower (S0S) and upper (S0V) significant levels.

The preliminary processing occurs on the FNOC front-end computers. At the start of the operational run, the observation types used by the operational atmospheric analyses are unpacked, scaled to the proper physical units, and written out as ASCII records to a sequential file. The data formats used are essentially those agreed upon for the international exchange of meteorological observations during the First GARP[1] Global Experiment (FGGE) in 1979. Appendices A and B contain the subset of data formats applicable for the observations used by the FNOC operational atmospheric analysis and predication systems. The code tables referred to in Appendix B are the standard WMO code tables (WMO, 1988). The FGGE format has been followed as closely as feasible; the only major exception is that a new format was defined for the DMSP SSM/I[2] geophysical observations.

The sequential file of observations in FGGE format is then transferred to the Cyber 205, where the actual quality control of the observations is performed. The quality controlled observations and the corresponding quality flags are written out in the FGGE format as CRANDIO records on the operational file, ADPFNOC. Each record is uniquely identified with a FNOC

[1]Global Atmospheric Research Program

[2]The Special Sensor Microwave Imager is flown aboard the Defense Meteorological Satellite Program's F-8 satellite.

Data type	ADPFILE record identifier
Radiosondes (mandatory 100 mb and below)	S0M
Radiosondes (significant below 100 mb)	S0S
Radiosondes (mandatory above 100 mb)	S0U
Radiosondes (significant above 100 mb)	S0V
Pilot balloons	PIB
Satellite soundings (thickness)	S0F
Satellite soundings (temperature, up to 50 mb)	S0G
Satellite soundings (temperature, above 50 mb)	S0H
Satellite cloud-tracked winds	TSX, TWX
Australian sea-level pressure bogus	PAB
Marine (synoptic) observations	SHX
Land (synoptic) observations	SMX
Aviation hourlies (U.S. and Canada airways)	SAX
METAR (international airways)	MTR
Aircraft reports	S0A
Reconnaissance aircraft reports	S0B
SSM/I geophysical data records	SS5

Table 1: ADPFILE record identifiers according to observation type.

standard record label containing the observation type catalog name, date-time-group and record continuation indicator. The CRANDIO record names are the same as previously described and are shown in Table A.1. The record continuation indicator is the same as the "tau" indicator and is incremented for subsequent records of a given observation type with same date and time. Individual reports are not allowed to cross the CRANDIO record boundaries. The radiosonde quality control occasionally provides substitutions for erroneous values. The correction is integrated within the radiosonde report. The report header and the data line containing the original erroneous observation are written to the end of the same CRANDIO record. There must be at least one blank line between the last report on a record and any replaced original values. An example of a radiosonde report with corrections is shown in Figure 1. Further information on the ZRANDIO and CRANDIO file conventions may be found in the FNOC Computer User Guide (FNOC, 1974).

2.1 Observation types

The observation types that are retrieved from ADPFILE, quality checked and stored in the operational atmospheric data base are listed below. The numbers of observations are typical for a ±3 hour time window centered on 12 UTC. Reports continue to arrive for several hours after the observing

```
*1140375 771  2840 36609990110512 0  41
1010000     95 1-999 9-999 9-99-99 9   2
 1 9270    771 6  308 1  300 1-99-99 9   3
10 8500 1540 1  226 1  290 1-99-99 9   4
 2 8280 1760 6  204 1  268 1-99-99 9   5
10 7000 3180 1    76 1  160 1-99-99 9   6
 2 6540 3729 6    24 1  120 1-99-99 9   7
 2 6150 4223 6    -3 1  220 1-99-99 9   8
 2 6110 4275 6    -5 1  220 1-99-99 9   9
 2 5430 5203 6  -87 1  140 1-99-99 9  10
 2 5350 5318 6  -87 1  240 1-99-99 9  11
 2 5100 5687 6-101 1  180 1-99-99 9  12
10 5000 5850 1-105 1  220 1-99-99 9  13
 2 4860 6058 6-107 1  468 1-99-99 9  14
 2 4830 6106 6-107 1  308 1-99-99 9  15
 2 4680 6347 6-129 1  180 1-99-99 9  16
 2 4070 7397 6-199 1  348 1-99-99 9  17
10 4000 7530 1-207 1  340 1-99-99 9  18
 2 3350 8804 6-327 1  168 1-99-99 9  19
10 3000 9580 1-385 1  180 1-99-99 9  20
 2 279010065 6-433 1  128 1-99-99 9  21
10 250010810 1-455 1  220 1-99-99 9  22
 2 237011154 6-471 1  348 1-99-99 9  23
10 200012270 2-537 1  330 1-99-99 9  24
 2 158013750 6-611 1  308 1-99-99 9  25
10 15001081033-618 4  220 1-99-99 9  26
12 100016570 1-673 1  290 1-99-99 9  27
 2   76718128 6-719 1  280 1-99-99 9  28
10   70018690 1-725 1  270 1 99-99 9  29
 2   66318984 6-731 1  268 1-99-99 9  30
 2   56019998 6-629 1  300 1-99-99 9  31
10   50020710 1-619 1  300 1-99-99 9  32
 2   42021777 6-609 1  308 1-99-99 9  33
 2   35222887 6-563 1  320 1-99-99 9  34
 2   30223868 6-525 1-999 9-99-99 9  35
10   30023940 1-525 1-999 9-99-99 9  36
 2   23125605 6-509 1-999 9-99-99 9  37
10   20026590 1-473 1-999 9-99-99 9  38
 2   19526717 6-467 1-999 9-99-99 9  39
 2   10530864 6-419 1-999 9-99-99 9  40
10   10031220 1-999 9-999 9-99-99 9  41


*1140375 771  2840 36609990110512 0   2
10 150010810 5-455 3 220 0-99-99 9   2
```

Figure 1: Example of a radiosonde report that includes a correction followed by the original observation.

time, so that the actual numbers vary some according to the cut-off time. The observation counts tend to be higher than for other operational forecast centers because of the Air Force Global Weather Intercept Program. Listening stations throughout the world intercept and retransmit weather reports, allowing for more timely data receipts as well as more observations.

- Surface data, including land and ship synoptic reports, surface aviation observations (airways), and synthetic observations of sea-level pressure and/ or wind,
  1. Synoptic land (SMX) : 14,000
  2. Synoptic ship (SHX) : 2,400
  3. Airways (SAX) : 3,600
  4. Australian bogus (PAB) : 900
- Conventional multi-level upper data such as radiosondes (rawinsondes) and pilot balloons,
  1. Radiosondes (S0X) : 715
  2. Pibals (PIB) : 425
- Aircraft reports,
  1. Conventional aircraft observations (S0A) : 1,300
  2. Reconnaissance aircraft reports (S0B) : 10
- Satellite cloud-tracked winds, temperature soundings, precipitable water profiles and surface wind speed.
  1. Thicknesses and precipitable water soundings (S0F) : 6,400
  2. Layer mean temperature and precipitable water (S0G) : 3,600
  3. Layer mean temperature, above 50 mb (S0H) : 3,700
  4. Satellite cloud-tracked winds (TSX,TWX) : 1,800
  5. DMSP/SSMI sea-surface wind speeds (SS5) : 100,000

2.2 The FNOC master station list

Observations are transmitted with the appropriate World Meteorological Organization (WMO) block and station number. WMO block numbers are assigned according broad geographical and political regions as shown in Figure 2. The station numbers are assigned according to latitude and longitude and generally increase from west to east and the first digit of the triple digit station number increases from north to south. The United States and Canada

follow the opposite convention. The procedure is slightly different for fixed and drifting buoys. The block number indicates the region of deployment as indicated in Figure 3. Members of the WMO who plan to disseminate buoy data on the GTS are assigned blocks of numbers; these numbers make up the station index. For drifting buoys, 500 is added to the assigned station index (WMO, 1988).

The block and station number must exist in the master station list in order for the observation to be decoded and stored in ADPFILE. For land stations, the station location and elevation are appended to the observations which are then decoded and stored in ADPFILE. The master station list used by FNOC is maintained by the Air Force at Carswell Air Force Base and is updated approximately every two weeks. The station locations or elevations in the master station list sometimes differ from those in the WMO station catalog (WMO,1990) because station locations and elevations are not always known precisely, and must be estimated from other sources of information. Occasionally, a station will have an erroneous station elevation or location. The problem of an incorrect station elevation is important for radiosonde QC because it invalidates a powerful quality check of the mandatory height data.

Users should be aware that the latitudes and longitudes stored with the observations in ADPFILE are in degrees and tenths, while both the FNOC master station list and the WMO station index (WMO, 1990) report station locations in degrees and minutes.

3 Quality Control

The quality control for the operational atmospheric database consists of several main components. The first component is the objective quality control checks that are performed prior to the MVOI. Further quality checks are made within the MVOI. Several options are available for subjective intervention during the QC process.

The objective quality control procedures were adapted from those in use operationally at the European Center for Medium-Range Weather Forecasting (ECMWF)(Norris, 1991) and are similar to those in use at other operational centers worldwide. Some of the quality checks within this stage are based upon geophysical constraints such as hydrostatic balance, lapse rate limitations and climatological limits. Others evaluate the internal consistency of the report. Still others are based upon rules established by the World Meteorological Organization (WMO) for the exchange of meteorological observations (WMO, 1988). An example of the latter are the rules governing the selection of significant levels on a rawinsonde report. The quality control procedures within the analysis check the observation for consistency against the background field and with the adjacent observations. These procedures are described in Goerss and Phoebus (1991).

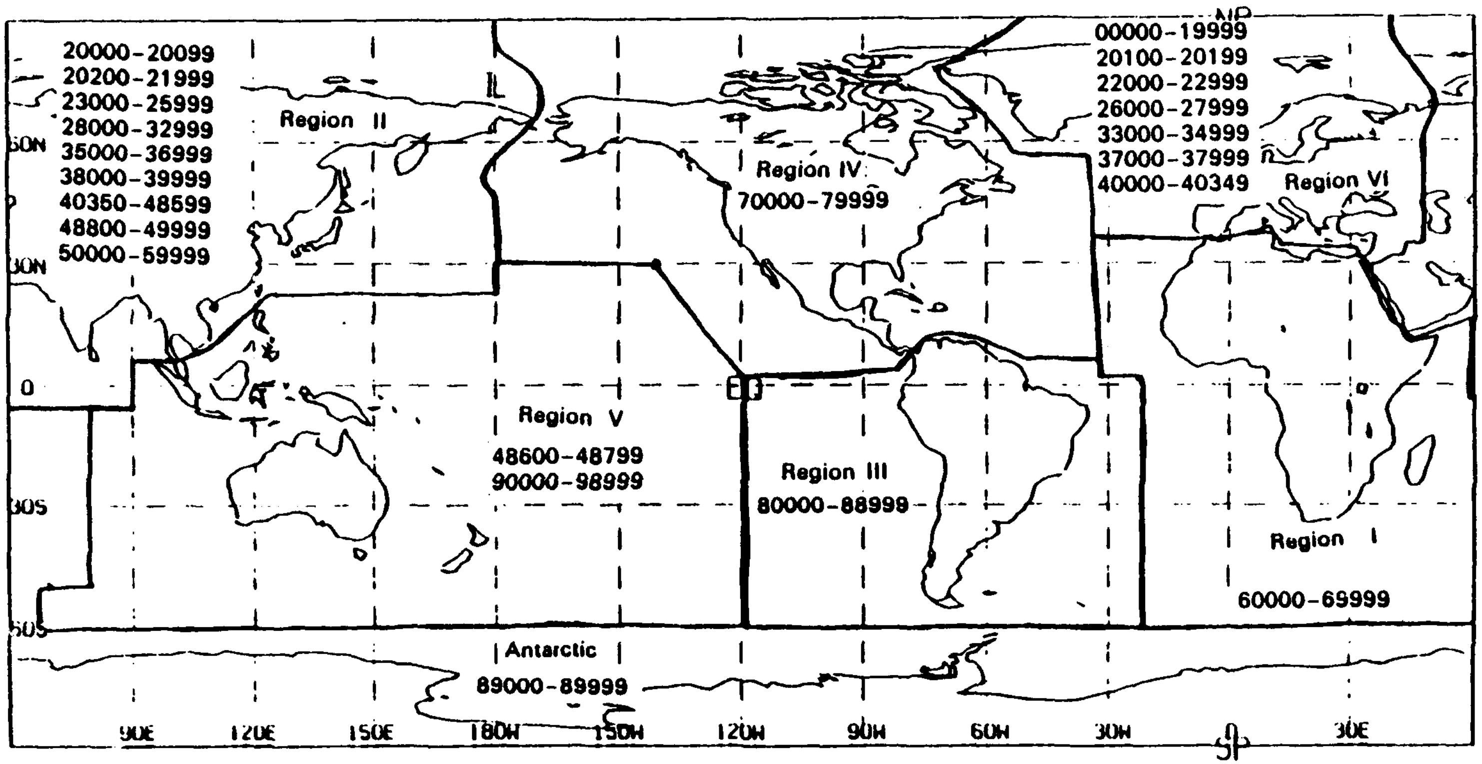

Figure 2: WMO regions and their associated block and station index numbers (*after WMO (1990)*).

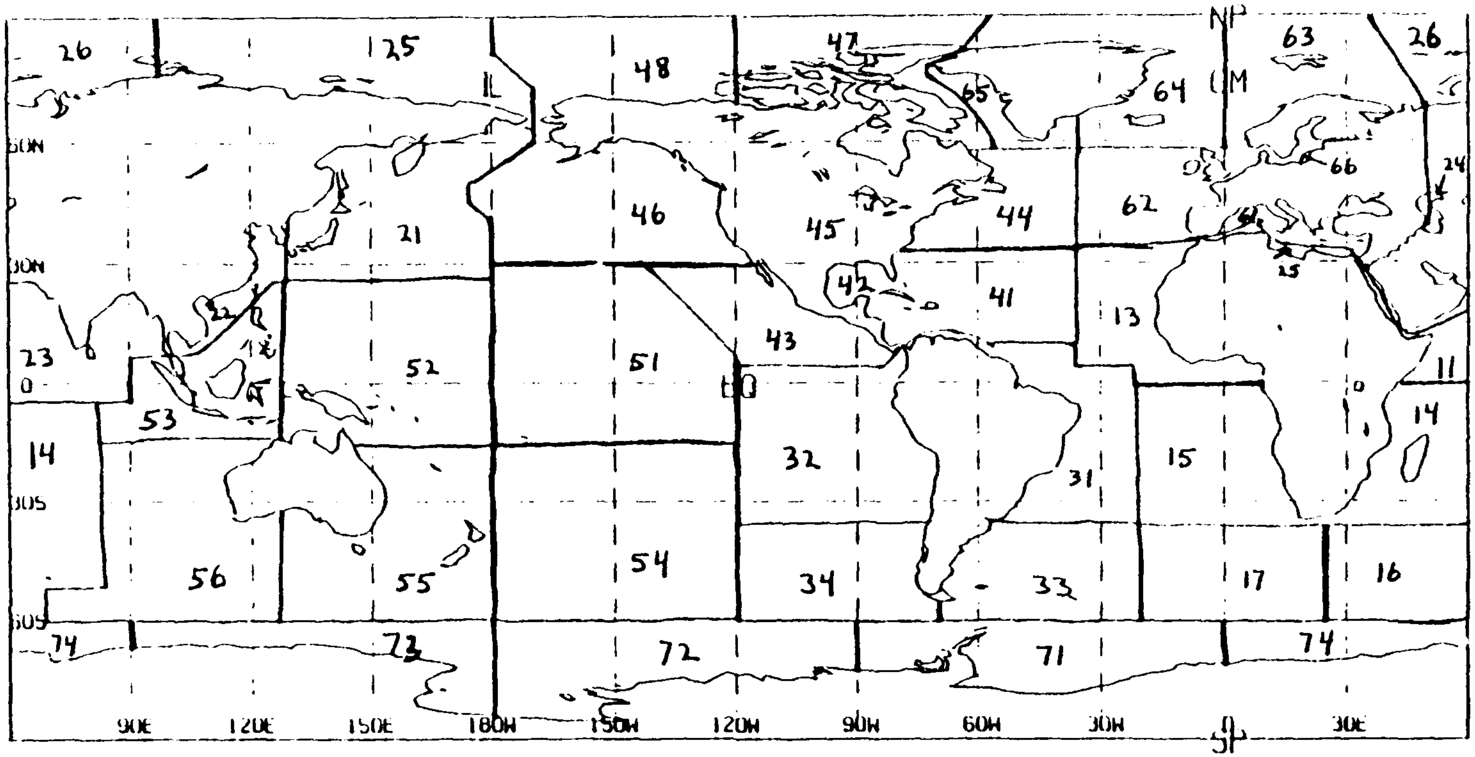

Figure 3: WMO regions and sub-areas in which marine observing platforms are deployed (*after WMO (1988)*).

The subjective quality control performed at FNOC in support of the atmospheric analysis and prediction systems is restricted to the rejection or blacklisting of marine observations. The sea-level pressure and/ or winds for marine observations of pressure or wind may be rejected in two ways. The first requires the Quality Control Duty Officer to specify the ship to be rejected. Any pressure or wind observation from that ship is rejected. No date and time are required with this option so the blacklisted ship will be rejected as long as its name remains on the list. The second alternative allows the user to specify a latitude and longitude, and either a wind speed and direction, or pressure, or both. This option also requires that the date and time of the observation to be rejected be indicated. Any ships within 1° of the given location *and* within 1 mb of pressure or 30° and 5 $\mathrm{m\,s^{-1}}$ for the wind will be rejected for that parameter.

There are two main flaws in this procedure at present. When the QC program is run in non-operational mode, the current ship reject list is read and any ship whose name appears on the list will be rejected. The second flaw occurs during operational runs when more than one ship is within 1° of the indicated position and its observation falls within the allowed tolerances. Each ship rejected by this second method will generally reject a second, good observation with it.

An option to generate synthetic observations of sea-level pressure and wind bogus is available for NOGAPS (Goerss, 1988). It is intended to help the forecast model better define rapidly deepening oceanic cyclones by providing additional observations over the data-sparse oceans. Based on satellite imagery analysis, the Quality Control Duty Officer specifies the central pressure and position. Dynamically consistent synthetic observations are automatically generated and a local MVOI analysis utilizing the synthetic observations is performed so that the impact of the synthetic observations may be evaluated and a final accept/ reject decision made. Synthetic observations to help NOGAPS more accurately forecast tropical cyclones are generated automatically from the warnings put out by Joint Typhoon Warning Center in Guam. The synthetic observations consists of a 1000 mb height report and winds at the mandatory pressure levels up to 400 mb.

The parameters listed in the following sections are in standard WMO notation. The reader is referred to WMO (1988) for parameter definitions and code tables. The severity of an error is indicated with T = trivial, S = serious and F = fatal.

3.1 Quality flags

Each observation within a report (e.g. temperature or height) has a quality flag determined by the objective and analysis QC procedures. The quality flags are set according to the severity of the error detected and assigned according to FGGE specifications. The quality control procedures described

Internal Flag	FGGE Flag
0 : value correct	0: QC not done
1 : probably correct	1: good
2 : probably wrong	2: suspect
3 : value wrong	3: bad

Table 2: Flag definitions.

by Norris (1991) use four degrees of confidence, while the FGGE format allows only three. Four levels of confidence are used internally within the QC algorithms and are converted to FGGE confidence flags in accordance with Table 2. Depending upon observation type, the flags may be set directly by a given test, or as the result of a series of tests. The quality flags differ slightly in meaning for the different observation types. The tables in Appendix A show the definition of the quality flags. The NOGAPS MVOI determines the analysis quality flags for the operational atmospheric database. The single quality flag option determined by the MVOI is a "reject" flag, and it is set only for observations that have been both considered *and* rejected by the analysis. Thus, observations that have a blank analysis quality flag may not have been considered by the analysis and may be incorrect. Some observation formats allow for only a single quality flag. In that case, an analysis "reject" quality flag will overwrite the objective quality flag.

Unless otherwise noted, counters associated with each observation within the report are incremented each time a test is failed. A "trivial" error increments the counter by 1, a "fatal" error increments the counter by 4. At the end of all the tests, 1 is deducted from each counter (greater than 1), and the QC flag is set equal to that value, subject to a maximum value of three. This yields the ECMWF type QC flag which is converted to a FGGE type flag at the end of the quality checking as indicated in Table 2. In some cases, erroneous values may be replaced by likely substitutions. Then, original value is flagged as rejected and retained.

3.2 Treatment of duplicate reports

Frequently, identical or nearly identical reports will arrive from the same station with the same observation time. FNOC receives the global set of all radiosonde, pilot balloon, and surface land and ship reports from both the NMC-FNOC data link and the AWN. This automatically gives at least one duplicate. Exact duplicates are removed prior to storage in ADPFILE and the nearly identical reports by the QC system. The source of these near duplicates varies. They may be corrections for earlier, incorrect observations or the may be the same observation inserted onto the GTS at different nodes

and slightly corrupted by transmission errors. The QC program attempts to determine which one of the near duplicates is most likely to be a correction, or most likely to be valid. A rigorous procedure has been implemented to handle these near duplicates for surface observations. Radiosondes also have this problem, but the decision making algorithm is complicated by the need to evaluate each datum with the adjacent pressure level data. The selection algorithm for radiosondes will be implemented with the operational QC for meteorological observations on the next generation of computers. For surface observations, the near duplicates are handled by the following methods:

1. All of the near duplicates are quality checked.
2. The first report is compared to the second according to this observation priority: pressure, wind direction, wind speed, temperature, dew point depression, pressure tendency and water temperature (for marine observations). The order was established according to MVOI analysis priority and restricted to observations that are quality checked and have quality flags associated with them. If an observation is accepted in one report but is rejected (or missing) in the other report, then the appropriate report is eliminated and the remaining one is compared with any other near duplicates.
3. If no report has been selected after examining the seven priority observations, the remaining non-checked observations are examined for missing data. If the procedure encounters missing data for one report and not the other, the one without the missing data is chosen.
4. If no report has been chosen, then the last report is selected.
5. If more near duplicates are available, the procedure now compares the current "best" observation with the next.

Typically, 10% of the ships have nearly identical duplicate reports; the average number of the near duplicates is 2. Approximately 6% of the land synoptic stations report nearly identical duplicates with an average number of near duplicates per station of 2.5. Only 3% of the airways stations transmit almost identical reports which invariably consist of the original report and (most likely) the retransmission of a corrected report.

3.3 Surface reports

The surface data types processed by the QC system are land and ship synoptic reports, surface aviation observations and the Australian sea-level pressure synthetic observations (PAOBS). The PAOBS are used only in the post-time NOGAPS runs due to late data receipt. The international equivalent of the

aviation hourlies are the METAR reports. A switch is available in the QC program to turn on processing of the MTR records. They are not currently used in the NOGAPS unclassified run.

The surface observations from the FNOC SMX, SHX and SAX records do not store the thousands or hundreds digit of pressure or height. That is, a pressure of 1045.2 mb will be stored as 452. This creates an ambiguity, as the above pressure could also be 945.2 mb. Users should be aware of this and realize that two values or more are possible and the correct one must be selected. For atmospheric data assimilation systems, the ambiguity is resolved in the analysis where both possible values are compared to the first guess, and the one closest to the first guess is accepted. Land stations that report station pressure are not checked by the objective QC because of this. In the analysis, the station elevation and standard atmosphere are used to calculate the station pressure and thus recover the leading digits. This value is then converted to a thickness and used at the nearest analysis pressure level.

Because of an error in the decoder for the SAX records, if the reported temperature is greater than or equal to 100°, the temperature is stored as missing. In addition, United States stations report the temperature in units of degrees Fahrenheit, while Canadian stations report the temperature in degrees Celsius. Since no straightforward method exists to differentiate these observation without the use of a background field, all observations are treated as reporting in degrees Fahrenheit and are converted to degrees Celsius. Both of these problems could adversely affect the MVOI analyses since the temperatures are used to calculate the 1000 mb heights which are used in the analysis.

At the present time, all of the coastal and marine observations are grouped together in ADPFILE on the SHX record. The QC program uses the conventions for naming stations to distinguish between ships, fixed and drifting buoys and C-MAN (coastal marine) stations. Each of these are assigned unique identifiers according to Table A.2. A ship that reports zero speed is assigned a fixed ship identifier, otherwise it is a mobile ship. FNOC translates the WMO five digit block station number for drifting buoys into a five character name where "A" corresponds to "0"; "B" corresponds to "1", and so on. The permanent weather ships are no longer uniquely identified by the names "C7C ", "C7M ", etc. Instead, they now transmit the name of the actual ship taking the observations and are identifiable by location.

All observations are checked against plausibility or gross error limits. The gross error tolerances are set slightly greater or smaller than the record observed maximum or minimum values for a parameter. For example, the minimum and maximum plausibility limits for land temperatures are −90 °C and 60 °C, respectively. Historically, the minimum recorded temperature was −89 °C at Vostok, Antarctica and the maximum recorded temperature was

FGGE pressure code indicator	Min (ppp or $HHHH$)	Max (ppp or $HHHH$)
0 (ppp =sea level)	880 mb	1080 mb
1 (ppp =station level)	*	*
6 ($HHHH$ = 850 mb)	250 m	2100 m
7 ($HHHH$ = 700 mb)	1600 m	3800 m
8 ($HHHH$ = 500 mb)	3800 m	6600 m
9 type unknown	*	*

Table 3: Minimum and maximum permitted pressure or height values for surface data given pressure level indicator. A "*" indicates that the value is not checked against limits.

58 °C at El Azizia, Libya (Riordan and Bourget, 1985). At the present time, the plausibility limits do not vary with seasons. The observations are also checked for internal consistency. An example of a violation of internal consistency would be a station reporting variable wind direction and a wind speed greater than 6 $\mathrm{m\,s^{-1}}$.

No substitutions are provided for erroneous surface data except for ship position which may be corrected as a result the operational ship tracking program at FNOC. Based upon its previously reported positions, the allowable region for a ship's location is calculated. Ships that report a position outside of this region may have their position corrected, or the ship position QC flag set to reject. The new position must resemble the position originally reported, i.e. 25.2 °N, 130.0 °E could be replaced with 25.2 °N, 130.0 °W. The reports are subjectively evaluated if only two reports from the same ship are available and they are in disagreement.

The quality checks for surface data are as follows:

i) Pressure and geopotential height ppp , $HHHH$

Ship only: pressure level code $\neq 0$ .... F
Ship only: $ppp < 880$ or $ppp > 1080$ mb .... F
Land only: $ppp < ppp_{min}$ or $ppp > ppp_{max}$ .... F
Land only: $HHHH < HHHH_{min}$ or $HHHH > HHHH_{max}$ .... F
where the pressure and height limits depend upon pressure level code indicator and are given in Table 3.

ii) Wind direction and speed dd , FF

$dd < 0$ or $dd > 360$ and dd not variable .... F
dd missing, FF not missing .... T
dd not missing, FF missing .... T
$dd = 0, FF \neq 0$ .... F
$dd \neq 0, FF = 0$ .... F
dd =variable, $FF > 3\,\mathrm{m\,s^{-1}}$ .... T

dd =variable, $FF > 6\,\mathrm{m\,s^{-1}}$ .... F
$FF \geq 45\,\mathrm{m\,s^{-1}}$ .... F

iii) Air temperature and dewpoint TT , T_dT_d

$TT < -90$ °C or $TT > 60$ °C .... F
$T_dT_d < -90$ °C or $T_dT_d > 60$ °C .... F
$TT > T_dT_d + 1$ °C and $42 \leq ww \leq 49$ .... T
$TT < -2$ °C and $50 \leq ww \leq 55$ or $58 \leq ww \leq 65$
or $68 \leq ww \leq 69$ or $80 \leq ww \leq 82$ .... T
$TT > 6$ °C and $68 \leq ww \leq 79$ or $83 \leq ww \leq 88$ .... T
Land only: $TT < T_dT_d$ .... T
Land only: $TT - T_dT_d > 50$ °C .... T
Ship only: $TT < T_dT_d - 1$ °C .... T
Ship only: $TT - T_dT_d > 30$ °C .... T

iv) Pressure tendency and magnitude a , pp

$pp = 0$ and $a \neq 0, 4$ or 5 .... T
$a = 4$ and $pp \neq 0$ .... T
$pp < -40$ mb or $pp > 40$ mb .... F

v) Sea-surface temperature T_wT_w

$T_wT_w < -2$ °C or $T_wT_w > 40$ °C .... F

3.4 Aircraft observations

Both conventional and reconnaissance aircraft data are processed by the QC program, however only the conventional aircraft observations are used by NOGAPS. The reports with identification number of "XX999" are either aircraft observations that arrived at Carswell without identification or pilot reports that are converted to the AIREP format at Carswell. The raw aircraft reports in ADPFILE do not carry information as to the type of original report, i.e. voice transmission versus keypad entry versus automated observing and relay systems. The quality of the data varies dramatically. Studies have indicated that typical rejection rates vary from greater than 30% for voice transmission reports to less than 1% for the fully automated systems (Brewster et al. 1989).

All observations are checked against climatological limits, as well as for internal consistency. No substitutions are provided for erroneous observations.

The quality tests for aircraft observations are:

i) Geopotential height $HHHH$

$HHHH < 10$ m or $HHHH > 25{,}000$ m .... F

HHH(m)	TT_{min}(°C)	TT_{max}(°C)
$9900 \leq HHH$	-100	0
$7800 \leq HHH < 9900$	-100	0
$6100 \leq HHH < 7800$	-90	5
$4700 \leq HHH < 6100$	-90	13
$3270 \leq HHH < 4700$	-90	20
$2280 \leq HHH < 3270$	-90	27
$1500 \leq HHH < 2280$	-90	34
$HHH < 1500$	-90	60

Table 4: Maximum and minimum temperatures allowed (given height) for aircraft data.

ii) Air temperature TT

$TT < TT_{min}$ or $TT > TT_{max}$ or HHH already flagged 3 .... F

where TT_{min} and TT_{max} depend on HHH and are given in Table 4.

iii) Wind direction and speed dd, ff

dd missing, FF not missing .... T

dd not missing, FF missing .... T

$dd < 0$ or $dd > 360$ and dd not variable .... F

$dd = 0, FF \neq 0$ .... F

$dd \neq 0, FF = 0$ .... F

dd variable and $FF > 3\,\mathrm{m\,s^{-1}}$ .... T

dd variable and $FF > 6\,\mathrm{m\,s^{-1}}$ .... F

dd or FF present but HHH already flagged 3 .... F

$FF > FF_{max}$ .... F

$FF > 0.8FF_{max}$ .... S

where FF_{max} is given by Table 5.

3.5 Satellite temperature and moisture retrievals

The TOVS soundings from the NOAA satellites[3] and the SSM/T[4] soundings from the DMSP satellites are both processed by the QC program. The header for each retrieval contains the satellite identification number as indicated by Table A.5. These are the same satellite identifiers used by FNOC on ADPFILE and are subject to change when new satellites become operational and old ones fail.

[3]National Oceanic and Atmospheric Administration TIROS Operational Vertical Sounder

[4]Special Sensor Microwave Temperature

HHH (m)	$FF_{max}(\mathrm{m\,s^{-1}})$
$12,000 \leq HHH$	130
$9000 \leq HHH < 12,000$	154
$5500 \leq HHH < 9000$	128
$3000 \leq HHH < 5500$	103
$1500 \leq HHH < 3000$	70
$1200 \leq HHH < 1500$	65
$HHH < 1200$	60

Table 5: Maximum permitted wind speeds for aircraft data.

The satellite soundings are generally in good condition with respect to gross errors o. communication errors upon arrival at FNOC. FNOC receives satellite soundings from NESDIS via two different links. The S0F records arrive via Carswell Air Force Base and are include layer thicknesses up to 1 mb and precipitable water up to 300 mb. The S0G and S0H records are transmitted directly from the National Meteorological Center to FNOC and contain the soundings in terms of layer mean temperatures and precipitable water up to 50 mb in the S0G record and from 50 to 0.4 mb in the S0H records. The precipitable water is from the surface to 300 mb. The DMSP instruments report up to 10 mb only. The MVOI analysis uses the S0F records and assimilates the thicknesses directly. This avoids the problem of assigning a base pressure to convert thicknesses to heights. The S0G records are redundant with the S0F retrievals and are processed only as a backup if the data link with Carswell is down. The quality and reliability of the S0F records appears to be better than that of the S0G records. Another advantage of the S0F records is that they contain the complete sounding up to 10 mb (as required by the NOGAPS MVOI); use of the S0G records requires that they be co-located with the corresponding S0H retrieval for completeness.

The present ADPFILE format allows for the storage of one base pressure. However, the soundings are transmitted with two base pressures; one applicable for the thicknesses or temperatures, and the other, for precipitable water. ADPFILE stores the base pressure for thicknesses (temperatures). The base pressures are usually the same, but are occasionally different. Using the thickness (temperature) base pressure typically gives an illogical structure (such as an 820 to 850 mb thickness) and the entire sounding is flagged as "suspect".

Satellite temperature retrievals tend to have poor vertical resolution in the troposphere, and errors in the lower levels tend to be compensated for by errors of the opposite sign in the upper levels (Gallimore and Johnson, 1986). The analysis compares the lapse rate of the retrieval against that of

the analysis background. The data below 300 mb is flagged as "bad" for those retrievals that deviate excessively from the background. The errors in satellite retrievals also tend to be horizontally correlated, so the satellite retrievals do not undergo the same horizontal consistency checks as the other observations.

All observations are checked against climatological limits, as well as for internal consistency. For satellite soundings, the individual levels are not flagged. Rather, the entire sounding retains an overall quality flag. Any error in the precipitable water results in a FGGE quality flag of "suspect"; any error in temperature or thickness results in a quality flag of "bad". The majority of the errors caught by the objective QC are errors introduced by the data decoders. No substitutions are provided for erroneous data.

For each level of the satellite sounding, the QC checks are:

Base pressure $p_ap_a < 0$ or $p_ap_a > 1080$ mb .... F
Upper pressure $p_ip_i < 0$ or $p_ip_i > 1080$ mb .... F
Mean temperature $\overline{TT} < \overline{TT}_{min}$ or $\overline{TT} > \overline{TT}_{max}$ .... F
Precipitable water $www < 0$ or $www > www_{max}$ .... F
Thickness $t_lt_lt_l \leq 0.5 t_lt_lt_{lmax}$ or $t_lt_lt_l > t_lt_lt_{lmax}$ .... F

In the above tests, $\overline{TT}_{min}$ is the mean of the minimum temperatures for $p_ap_a, p_ap_a + 100, \ldots, p_ip_i - 100$ as given by Table 6. The value $\overline{TT}_{max}$ is computed similarly. Precipitable water is calculated assuming saturation at the maximum allowed temperatures. The value www_{max} is given by Table 7 and is summed between the base pressure and upper pressure. Pressures (and corresponding precipitable water values) at non-standard pressure levels are interpolated. The thicknesses are computed from the hypsometric equation where $t_lt_lt_{lmax}$ is the sum of the thicknesses between the base and upper levels given in Table 7. Non-standard level pressures and thicknesses are interpolated.

3.6 Satellite cloud-tracked winds and sea-surface winds

Satellite cloud-tracked winds from the geostationary satellite and DMSP/SSMI surface wind speeds over the oceans are both processed by the QC program. The FNOC record TSX contains the satellite cloud-tracked wind from Japan, the European Space Agency, and occasionally a few from India. These latter observations are from 06 UTC and 18 UTC, arrive late, are few in number and of poor quality. They probably never arrive in time to be used operationally in NOGAPS. The TWX records contain the NESDIS cloud-tracked winds from the U.S. GOES (Geostationary Operational Environment Satellite) satellite.

The SS5 geophysical data records contain sea-surface wind speeds and various moisture parameters. The records are thinned by a factor of 6 during the preprocessing stage. Of the remaining records, only the ones with a

ppp (mb)	TT_{min}(°C)	TT_{max}(°C)
$ppp < 100$	-100	0
$100 \leq ppp < 200$	-100	0
$200 \leq ppp < 300$	-100	0
$300 \leq ppp < 400$	-100	0
$400 \leq ppp < 500$	-90	5
$500 \leq ppp < 600$	-90	13
$600 \leq ppp < 700$	-90	20
$700 \leq ppp < 800$	-90	27
$800 \leq ppp < 900$	-90	34
$900 \leq ppp < 1000$	-90	60
$1000 \leq ppp < 1100$	-90	60

Table 6: Maximum and minimum temperatures for satellite soundings.

Layer (mb)	Thickness $t_l t_l t_{lmax}$ (m)	Precipitable water www_{max} (mm)
1000-850	1541	106
850-700	1718	36
700-500	2884	27
500-400	1880	20
400-300	2382	15
300-250	1509	9
250-200	1847	4
200-150	2382	0
150-100	3357	0
100-70	2953	0
70-50	2786	0
50-30	4229	0
30-20	3357	0
20-10	5739	0
10-7	3057	0
7-3	7263	0
3-1	9739	0

Table 7: Maximum permitted thicknesses and precipitable water for layers between standard pressure levels.

ppp (mb)	TT_{min}(°C)	TT_{max}(°C)	FF_{max}($\mathrm{m\,s^{-1}}$)
$ppp < 200$	-100	0	130
$200 \leq ppp < 400$	-100	0	154
$400 \leq ppp < 500$	-90	5	128
$500 \leq ppp < 600$	-90	13	103
$600 \leq ppp < 700$	-90	20	103
$700 \leq ppp < 800$	-90	27	70
$800 \leq ppp < 850$	-90	34	70
$850 \leq ppp < 900$	-90	34	65
$1000 \leq ppp < 1080$	-90	60	60

Table 8: Maximum and minimum temperatures and wind speed tolerances for satellite cloud-tracked winds.

valid wind speed and a rain flag indicating wind speed errors of 2 $\mathrm{m\,s^{-1}}$ or less are transferred to ADPFNOC. This reduces the total number of wind speed observations for a ±3 hour time window to about 16,000. The SS5 geophysical data are quality controlled prior to storage in SATFILE. Any observations that falls outside of reasonable limits are pre-defined by the original processing to be out- of-limits. Therefore, the only other quality control performed on the SSM/I wind speeds is within the MVOI.

All observations are checked against climatological limits, as well as for internal consistency. No substitutions are provided for incorrect observations.

For satellite cloud-tracked winds, the error checks are:

i) Atmospheric pressure ppp

$ppp < 0$ or $ppp > 1080$ mb .... F

ii) Wind direction and speed dd , FF

dd missing, FF not missing .... T

dd not missing, FF missing .... T

$dd < 0$ or $dd > 360$ and dd not variable .... F

$dd = 0, FF \neq 0$ .... F

$dd \neq 0, FF = 0$ .... F

$FF > FF_{max}$ .... F

$FF > 0.8FF_{max}$ .... S

iii) Temperature TT

$TT < TT_{min}$ or $TT > TTmax$ .... F

where FF_{max}, TT_{min} and TT_{max} depend upon ppp and are given by Table 8.

3.7 Radiosonde observations

Radiosonde observations determine the vertical temperature and humidity profiles of the atmosphere as a function of pressure. A rawinsonde report includes wind velocity measurements as well. The terms radiosonde and rawinsonde are used interchangeably within this report. Radiosondes are probably the single most important observation source available. For this reason, the most effort is expended on them and they are discussed in greater detail here.

The WMO has established rules for the international exchange of radiosonde observations. Specific criteria apply to the selection of mandatory and significant levels in a radiosonde observation. For example, all stations must report mandatory level information. In addition, a sufficient number of significant levels must be selected so that the reported sounding reproduces the recorded sounding trace to within certain limits. Requirements also exist for the delineation of significant inversions. These rules provide the basis for the radiosonde quality checks of this section.

The quality control procedures closely follows those in use at the ECMWF as described by Norris (1990). The order in which these checks are performed is critical because a decision must be made whether an observation that is flagged as suspect or bad by a particular check will be considered further. Data that is rejected by one check may be validated by a later check, or it may erroneously allow adjacent observations to be rejected. The quality flags for each observation are set directly by the individual tests (as opposed to a system of counters) so that the QC flags reflect the most recent quality assessment. In general, the checks proceed from crude to more refined so that obvious errors are eliminated early on. The priority is on the validation of the mandatory levels since they are the primary ones used by the analyses. Substitutions may be provided for erroneous observations, but in all cases, the original is retained with a flag of "reject". In general, substitutions suggested by one step replace only data flagged as rejected by a prior step.

The tests below refer to the radiosonde observations parts A, B, C and D. The mandatory and significant level data from 1000 mb to 100 mb are contained in parts A and B, respectively. The mandatory and significant level data above 100 mb are contained in parts C and D, respectively.

The Taiwan radiosonde observations arrive twice with different block and station numbers; once with a Chinese block number and once with a Taiwanese block number. The reports are generally not identical. For example, station 58968 is the same as station 46692 and station 59553 is the same as station 46747. Both reports are processed for each station.

The rawinsonde instruments in use by the United States and Canada are sensitive to solar radiation striking the thermistor. The subsequent temperature errors lead to systematic errors in the calculated geopotential heights. Radiation bias corrections for these rawinsondes are determined and ap-

plied within the analysis. The original (not corrected) report is stored in ADPFNOC. The corrections are based upon the International Radiosonde Intercomparison Tests (Nash and Schmidlin, 1987), estimates of the observational biases, and solar elevation angle. The Chinese rawinsonde instrument has a marked bias that is corrected for within the MVOI as well. Corrections for other radiosonde instruments in use around the world are not yet made.

The radiosonde vertical consistency test proceed in the following order.

1. Start the vertical QC of one observation; all the available parts of the message are used.

2. Compare all values in the observation against climatological limits (section 3.7.1).

3. Check the lapse rate of the vertical temperature profile (section 3.7.2).

4. If parts B and/or D are available, then recompute the standard level data from the significant level data. Compare the reported standard pressure level data with the recomputed data. Adjust, if possible, the reported standard pressure level data (section 3.7.3).

5. Check for hydrostatic consistency between standard pressure levels (section 3.7.4).

6. Check for excessive wind shear control (section 3.7.5).

7. Vertical quality control is finished.

3.7.1 Climatological limits checks

All observations are compared against climatological or gross error limits. The limits represent the maximum and minimum observed values for each observation. At the present time, these values are fixed and do not vary with season or latitude. The climatological limits for radiosonde observations are presented in tables 9 through 12.

3.7.2 Lapse rate checks of vertical temperature profiles

Lapse rate QC checks the vertical temperature profile in the sounding for unreasonable lapse rates. The sounding is scanned layer by layer from the surface to the highest level. All mandatory and significant level temperature data are used. The lapse rate is allowed to be slightly superadiabatic. Extreme inversions are not permitted. If an unlikely lapse rate is detected, an attempt is made to determine which temperature is in error by examining the adjacent layers. If the error can be isolated, a change of sign for that temperature is tested and a substitution provided if appropriate. This test is

Surface Level	Range	Flag
Atmospheric pressure	$ppp > 1080$ mb	2
Air temperature	$TT < -90°C$ or $TT > 60°C$	2
Wind speed	$FF > 45\,\mathrm{m\,s^{-1}}$	2
Upper Level	**Range**	**Flag**
Temperature	$TT < TT_{min}$ or $TT > TT_{max}$	3
Dewpoint	$TT - T_dT_d < -1°C$ or $TT - T_dT_d > 50°C$	3
Wind speed	$FF > 0.8FF_{max}$	2
	$FF > FF_{max}$	3

Table 9: Clin. .tological limits checks where TT_{min} and TT_{max} depend on ppp and are given by Table 11, and where FF_{max} depends upon ppp if present, otherwise on HHH and is given by Table 12.

Level (mb)	Minimum height (m)	Maximum height (m)
1000	-350	400
850	900	1700
700	2400	3400
500	4400	6200
400	6000	7700
300	7700	10,000
250	9000	11,200
200	9900	12,800
150	12,000	14,600
100	14,500	17,000
< 100	15,000	35,000

Table 10: Maximum and minimum permitted heights for radiosonde mandatory pressure levels.

ppp (mb)	TT_{min}(°C)	TT_{max}(°C)
$ppp < 300$	-100	0
$300 \leq ppp < 400$	-100	0
$400 \leq ppp < 500$	-90	5
$500 \leq ppp < 600$	-90	13
$600 \leq ppp < 700$	-90	20
$700 \leq ppp < 800$	-90	27
$800 \leq ppp < 900$	-90	34
$900 \leq ppp < 1080$	-90	60

Table 11: Maximum and minimum permitted temperatures for various levels of the atmosphere.

ppp (mb)	HHH (m)	FF_{max} ($\mathrm{m\,s^{-1}}$)
$ppp < 50$	$22,000 < HHH$	160
$50 \leq ppp < 200$	$12,000 < HHH \leq 22,000$	160
$200 \leq ppp < 400$	$6500 < HHH \leq 12,000$	160
$400 \leq ppp < 500$	$5500 < HHH \leq 6500$	128
$500 \leq ppp < 700$	$3000 < HHH \leq 5500$	103
$700 \leq ppp < 850$	$1500 < HHH \leq 3000$	70
$850 \leq ppp < 1000$	$500 < HHH \leq 1500$	65
$1000 \leq ppp$	$HHH \leq 500$	65

Table 12: Maximum permitted wind speeds for various levels.

valuable for detecting and correcting sign errors. For each layer the following procedure is applied:

1. Use the temperature T_i at pressure p_i to extrapolate a new temperature T'_{i+1} at the pressure level p_{i+1} by the dry adiabatic lapse rate

$$T'_{i+1} = T_i(p_{i+1}/p_i)^{R/C_p}. \tag{1}$$

2. Compare the computed temperature T'_{i+1} with the reported temperature T_{i+1}. If $T_{i+1} \geq T'_{i+1}$ for $p_i \leq 500$ mb or $T_{i+1} \geq T'_{i+1} - 1$ for $p_i >$ 500 mb then the temperature profile (T_i, T_{i+1}) is ***not*** superadiabatic and the checking procedure continues on to the next layer. However, if the above is not satisfied at least one of the reported temperatures T_i or T_{i+1} must be erroneous. In order to determine which temperature is erroneous and correct the error if possible, it is necessary to use adjacent level data. The following algorithms are applied:

   (a) If $[T_{i+1} < T_{i-1}(p_{i+1}/p_{i-1})^{R/C_p}]$ and $[T_{i+2} \geq T_i(p_{i+2}/p_i)^{R/C_p}]$, the temperature T_{i+1} is marked as "erroneous", *Flag=3.*

   (b) If $[T_{i+1} \geq T_{i-1}(p_{i+1}/p_{i-1})^{R/C_p}]$ and $[T_{i+2} < T_i(p_{i+2}/p_i)^{R/C_p}]$, the temperature T_i is marked as "erroneous", *Flag=3.*

   (c) If $[T_{i+1} > T_{i-1}(p_{i+1}/p_{i-1})^{R/C_p}]$ and $[T_{i+2} > T_i(p_{i+2}/p_i)^{R/C_p}]$, the adjacent mandatory pressure level data is used to determine the error. The thicknesses between adjacent mandatory levels from the two profiles $(\ldots, T_{i-1}, T_{i+1}, T_{i+2}, \ldots)$ and $(\ldots, T_{i-1}, T_i, T_{i+2} \ldots)$ are computed. The profile which has a thickness that deviates the most from the reported thickness is considered in error and the corresponding T_i or T_{i+1} is marked as bad, *Flag = 3.*

   (d) If $[T_{i+1} < T_{i-1}(p_{i+1}/p_{i-1})^{R/C_p}]$ and $[T_{i+2} < T_i(p_{i+2}/p_i)^{R/C_p}]$, it is not sufficient to delete one of the temperatures T_i or T_{i+1} in order to get a profile which is not superadiabatic. Since this is an unlikely event and further testing is too complex, the check terminates and the flags for T_i and T_{i+1} are set to *Flag = 2.*

   (e) For all other possible combinations, no definite conclusions can be drawn, and the *flags are incremented by 1, subject to a maximum value of 3* for both T_i and T_{i+1}.

   (f) If an "error-marked" temperature would become correct according to lapse-rate control just by changing its sign, this change will be made and *the flag of the original set to 3.*

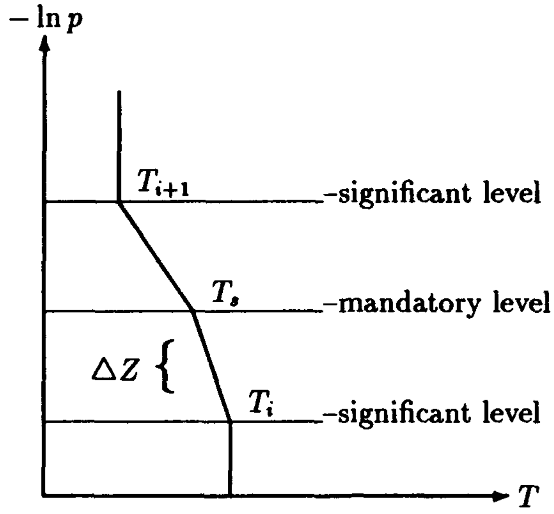

Figure 4: Temperature profile schematic of significant and mandatory pressure levels.

3.7.3 Consistency between mandatory and significant levels

The WMO (1988) reporting regulations require that a sounding must be reproducible to within specified limits from the significant level data alone. This redundancy of information gives an additional check on the reported mandatory pressure level data. In this step, the standard pressure level data are recomputed from the significant level data and compared with the reported standard pressure level data. The tolerances for the tests are given in Table 13. The adjacent significant levels must be within 100 mb of the mandatory level and the mandatory level must not be tagged as significant. In addition, this check is not used for dewpoint depression if the dewpoint depression falls below 30 °C at the level under consideration. Whenever possible, substitutions are provided for data previously determined to be in error. In practice, this procedure works quite well for temperatures and reasonably well for winds. The procedure inadequate for humidity because there is no distinction made between a significant level selected for temperature as opposed to humidity. The requirements for log-linearity still apply, but seem to be less stringently adhered to for humidity data. Regional coding practices (a' with the United States rawinsondes) sometimes dictate that the significant level wind information be transmitted independently in the PIBAL format (WMO, 1972). Since radiosonde and pilot balloon reports are not combined, this check cannot be used for these stations.

The checking procedure proceeds as follows:

1. Temperature and dew points are interpolated to the standard pressure

Parameter	Level	Limit
Height	Height > 6000 gpm	30 gpm
Height	Height $\leq$ 6000 gpm	20 gpm
Temperature	Below tropopause and below 300 mb	1.5 °C
Temperature	Above tropopause or above 300 mb	3.0 °C
Dew point temperature		10.0 °C
Wind speed		$25\,\mathrm{m\,s^{-1}}$
Wind direction	$FF \leq 5\,\mathrm{m\,s^{-1}}$ no limit, $FF > 5\,\mathrm{m\,s^{-1}}$	50°

Table 13: Limits for deviations for computed and reported standard pressure level data.

levels assuming a linear variation in $(\ln p)$ between the significant levels as shown in Figure 4. For example,

$$T_s = T_i + \frac{\ln(\frac{p_s}{p_i})}{\ln(\frac{p_{i+1}}{p_i})}(T_{i+1} - T_i). \tag{2}$$

2. Compute the virtual temperatures T^* at all mandatory and significant levels if possible. Then, starting from the surface level, compute the heights for all standard and significant levels assuming a linear variation of the virtual temperature in $(\ln p)$ as illustrated in Figure 4:

$$Z_{i-s} = \frac{R_d}{g}\frac{T_i^* + T_s^*}{2}\ln(\frac{p_i}{p_s}) \tag{3}$$

3. Winds at the standard pressure levels are interpolated from significant wind data assuming a linear variation wind components (u and v) in $(\ln p)$ between the significant levels.

4. The recomputed standard pressure level data are compared with the reported standard pressure level data. The limits in Table 13 for the deviations apply. If the differences between the recomputed values and the reported values exceed the limits, the corresponding quality flags are marked as "suspect", *flag = 2*, except for wind direction where the wind quality *flag is incremented by 1.*

5. If a standard pressure level temperature has flagged "suspect" by the checking procedure, an attempt is made to correct the temperature by changing the sign (i.e. +5 °C → −5 °C). If the correction gives a temperature within the limits if the recomputed temperature and if the absolute value of the correction is larger than 6 °C, a substitution is generated and the original value quality *flag is set to 3.*

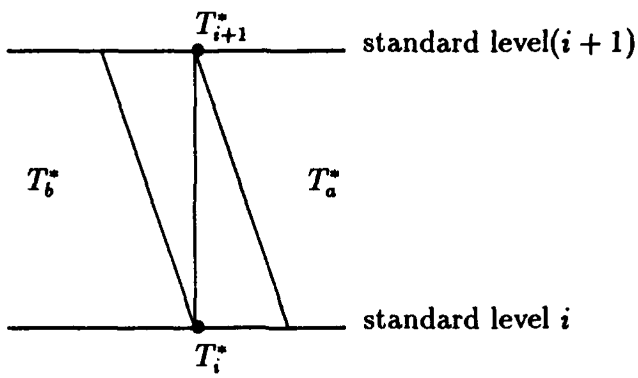

Figure 5: Temperature profile schematic showing warmest (T^*_a) and coldest (T^*_b) possible temperature.

6. Missing standard pressure level data are replaced with the recomputed values with the original value retained as missing.

3.7.4 *Hydrostatic consistency of radiosonde observations*

The hydrostatic equation is used to check the vertical consistency between the reported temperatures and geopotential heights at the standard pressure levels. The hydrostatic equation is one of the most powerful constraints for QC because of two factors: the atmosphere is in approximate hydrostatic balance, and the hydrostatic equation is used to calculate the geopotential heights at the mandatory levels in the original report. Hydrostatic QC is frequently able to produce good substitution for erroneous or missing data by interpolation from observations at the adjacent standard pressure levels. The hydrostatic quality check proceeds in the following steps:

1. The lapse rates between the standard pressure level temperatures are checked by a procedure similar to the one described in section 3.7.2. A slightly superadiabatic lapse rate is allowed; the temperature of any standard pressure level is allowed to be 0.5 °C below the temperature which is extrapolated from below by the dry-adiabatic lapse rate. A temperature exceeding the limits of this check is marked as erroneous, *flag = 3*.

2. If possible, virtual temperatures T^* at the standard pressure levels are computed. From the virtual temperatures (or the air temperatures

T'), thicknesses between the standard pressure levels are computed by assuming a linear variation in $(\ln p)$ of the temperatures between the standard pressure levels by

$$D_i = \frac{R_d}{g} \frac{T_i^* + T_{i+1}^*}{2} \ln(\frac{p_i}{p_{i+1}}). \tag{4}$$

3. Tolerances for the deviations between the reported and computed thickness are obtained by considering the most extreme temperature profiles in the layers between the standard pressure levels as shown in Figure 5. T_a^* is the warmest possible temperature profile assuming an inversion at level p_i and a dry adiabatic lapse rate in the layer. T_b^* is the coldest possible temperature profile, assuming a dry adiabatic lapse rate in the layer and an inversion at level p_{i+1}. This check is

$$|Z_{i+1} - Z_i - D_i| < TOL = K\left|\frac{D_a - D_b}{2}\right|, \tag{5}$$

where in practice K is given the value 0.75 since the very extreme temperature profiles T_a and T_b do not occur. The following restrictions on the testing tolerance TOL are used:

- Minimum value of TOL is 20 gpm
- Maximum value of TOL is 50 gpm below 400 mb.
- Maximum value of TOL is 80 gpm at and above 400 mb

If the testing algorithm is not fulfilled the corresponding layer is marked as erroneous which means that at least one of the values T_i, T_{i+1}, Z_i or Z_{i+1} must be erroneous.

4. In order to isolate the errors, the following error index is computed by for each error-marked layer:

$$E = \frac{Z_i - Z_{i-1} - D_{i-1}}{Z_{i+1} - Z_i - D_i}. \tag{6}$$

From the value of E, the following conclusions are made:

- $0.5 \le E \le 2.0$: T_i is probably erroneous
- $-2.0 \le E \le -0.5$: Z_i is probably erroneous
- $|E| > 2.0$: All heights above Z_i are probably erroneous
- If $|E| < 0.5$ it is difficult to draw any definite conclusions

The error marked heights and temperatures are recomputed by from the surrounding level data as described in 5 for temperatures and 6 for the heights. The recomputed element is again hydrostatically checked.

Temperatures are a so checked for extreme lapse rates and inversions. If the datum now satisfies the checking algorithm, the recomputed value is substituted. The original value is always retained with a *flag* = *3*.

5. The following methods are used to compute missing or error-marked standard pressure level temperatures. Whenever a standard pressure level temperature has been computed the resulting lapse rate is checked. If the computed temperature is more than 0.5 °C colder or 10 °C warmer (extreme inversion) than the temperature obtained by dry adiabatic extrapolation, the computed temperature is error-marked.

   - If only T_i is missing, compute downwards from level $i+1$ by

   $$T_i^1 = \frac{2g}{R_d} \frac{Z_{i+1} - Z_i}{\ln\left(\frac{p_{i-1}}{p_i}\right)}, \tag{7}$$

   and compute upwards from level $i-1$ with

   $$T_i^2 = \frac{2g}{R_d} \frac{Z_i - Z_{i-1}}{\ln\left(\frac{p_{i-1}}{p_i}\right)}. \tag{8}$$

   If neither of these temperatures fail the lapse rate check and $|T_i^1 - T_i^2| \leq 5$ °C, then both temperatures are used to compute an average temperature T_i . If only one temperature is error-marked, the non-marked temperature is used as T_i. When both of the recomputed temperatures, T_i^1 and T_i^2, are error-marked then

   $$T_i = T_{i-1} + \frac{\ln\left(\frac{p_{i-1}}{p_i}\right)}{\ln\left(\frac{p_{i-1}}{p_{i+1}}\right)}(T_{i+1} - T_{i-1}). \tag{9}$$

   If this temperature is also error-marked, the temperature T_i cannot be computed.

   - If both T_i and Z_i are missing, then

   $$T_i = \frac{2g}{R_d} \frac{Z_{i+1} - Z_{i-1}}{\ln\left(\frac{p_{i-1}}{p_{i+1}}\right)} - \frac{T_{i-1}\ln\left(\frac{p_{i-1}}{p_i}\right) + T_{i+1}\ln\left(\frac{p_i}{p_{i+1}}\right)}{\ln\left(\frac{p_{i-1}}{p_{i+1}}\right)}. \tag{10}$$

   If T_i is error-marked, a new T_i is obtained by (9). If neither of these temperatures are approved, the temperature T_i cannot be calculated.

   - If T_i and Z_i are missing together with Z_{i-1} and Z_{i+1}, then T_i is computed by (9).

- If T_i, Z_i and T_{i+1} are missing

$$T_{i+1} = \frac{2g}{R_d} \frac{Z_{i+1} - Z_{i-1}}{\ln\left(\frac{p_{i-1}}{p_i}\right)} - T_{i-1}, \tag{11}$$

and (10) is then used to compute T_i.

- If T_i and T_{i-1} are missing:

$$T_i = \frac{2g}{R_d} \frac{Z_i - Z_{i-2}}{\ln\left(\frac{p_{i-2}}{p_i}\right)} - T_{i+1}. \tag{12}$$

If T_i is error-marked, but level $i-2$ is complete and not error-marked then

$$T_i = \frac{2g}{R_d} \frac{Z_i - Z_{i-2}}{\ln\left(\frac{p_{i-2}}{p_i}\right)} - T_{i-2}. \tag{13}$$

If this T_i is now error-marked, the check of level i terminates. The check of level i terminates also if T_{i-2} or Z_{i-2} is missing.

- If T_i and Z_{i-1} are missing

$$T_i = \frac{2g}{R_d} \frac{Z_{i+1} - Z_i}{\ln\left(\frac{p_i}{p_{i+1}}\right)} - T_{i+1}. \tag{14}$$

If T_i is error-marked, a new T_i is computed by (9). The check of level i terminates if T_i is error-marked again.

- If T_i, Z_{i-1} and Z_{i+1} are missing: T_i is error-marked and the check of level i is terminated.
- If T_i and Z_{i+1} are missing

$$T_i = \frac{2g}{R_d} \frac{Z_i - Z_{i-1}}{\ln\left(\frac{p_{i-1}}{p_i}\right)} - T_{i-1}. \tag{15}$$

If T_i is error-marked, T_i is computed by (9). If T_i is error-marked again, the check of level i terminates.

- If T_i and T_{i+1} are missing

$$T_i = \frac{2g}{R_d} \frac{Z_i - Z_{i-1}}{\ln\left(\frac{p_{i-1}}{p_i}\right)} - T_{i-1}. \tag{16}$$

If T_i is error-marked, but T_{i+2} and Z_{i+2} exist (if not, the check of level i terminates) then

$$T_i = \frac{2g}{R_d} \frac{Z_{i+2} - Z_i}{\ln\left(\frac{p_i}{p_{i+2}}\right)} - T_{i+2}. \tag{17}$$

If T_i is error-flagged again, the check of level i terminates.

- If T_i, T_{i+1} and Z_{i+1} are missing, then T_i is computed by (16).
- If T_i, T_{i-1} and Z_{i-1} are missing, T_i is calculated by

$$T_i = \frac{2g}{R_d} \frac{Z_i - Z_{i-2}}{\ln\left(\frac{p_{i-2}}{p_i}\right)} - T_{i+1}. \tag{18}$$

For cases not covered above, the number of missing elements is considered too large and a reliable computation of the missing temperature cannot be performed.

6. Missing or error-marked height data are computed from above (Z_a) and or below (Z_b). If possible, virtual temperatures are used for the computation. The following methods apply:

- If only Z_i is missing:

$$Z_b = Z_{i-1} + \frac{R_d}{g}(T_i^* + T_{i-1}^*) \ln\left(\frac{p_{i-1}}{p_i}\right), \tag{19}$$

$$Z_a = Z_{i=1} + \frac{R_d}{g}(T_i^* + T_{i+1}^*) \ln\left(\frac{p_i}{p_{i+1}}\right). \tag{20}$$

  - If $|Z_b - Z_a| \leq 30$ gpm, then $Z_i = \frac{1}{2}(Z_b + Z_a)$
  - If $|Z_b - Z_a| > 30$ gpm but Z_a and Z_b are both accepted by the hydrostatic check of section 3.7.4, then $Z_i = \frac{1}{2}(Z_b + Z_a)$
  - If $|Z_b - Z_a| > 30$ gpm and only Z_b is accepted by the hydrostatic check: $Z_i = Z_b$.
  - If $|Z_b - Z_a| > 30$gpm and only Z_a is accepted by the hydrostatic check: $Z_i = Z_a$.
- If Z_i and data from level $(i-1)$ are missing, then $Z_i = Z_a$
- If Z_i and data from level $(i+1)$ are missing, then $Z_i = Z_b$

3.7.5 Vertical wind shear checks

The vertical wind shear control is applied for the wind data at standard pressure levels. The shear is checked in two ways:

1. A check of the wind speed shear
2. A check of a combination of directional shear and the sum of the wind speeds.

For the check of one standard pressure level wind, one more adjacent standard pressure level wind is needed. A counter system is utilized with four counters for each standard pressure level (SX, SXX, DX, DXX). S and D represent

Layer (mb)	< 30	≥ 30	≥ 40	≥ 50	≥ 60	≥ 70	≥ 80	≥ 90
1000 - 850 850 - 700 150 - 100 < 100	-	72	61	57	53	49	46	41
all others	-	110	84	77	70	63	52	50

Table 14: Maximum permitted sum of wind speed ($\mathrm{m\,s^{-1}}$) for various directional shears between two adjacent standard pressure levels.

speed and direction and the number of X's represents the severity. Depending on the results of each test, the counters are updated, and the final wind flag for each level is determined.

The speed shear tests are

- $|FF_1 - FF_2| > 20.6 + 0.275(FF_1 + FF_2)(\mathrm{m\,s^{-1}})$
  $SXX_1 = SXX_1 + 1$, $SXX_2 = SXX_2 + 1$
- $|FF_1 - FF_2| > 16.5 + 0.22(FF_1 + FF_2)(\mathrm{m\,s^{-1}})$
  $SX_1 = SX_1 + 1$, $SX_2 = SX_2 + 1$.

The directional shear tests are

- $FF_1 + FF_2 >$ MAXSUM ($\mathrm{m\,s^{-1}}$)
  $DXX_1 = DXX_1 + 1$, $DXX_2 = DXX_2 + 1$
- $FF_1 + FF_2 > 0.8$ MAXSUM ($\mathrm{m\,s^{-1}}$)
  $DX_1 = DX_1 + 1$, $DX_2 = DX_2 + 1$.

where MAXSUM depends on the directional shear DS between the standard pressure levels and on the pressure level and is given by Table 14.

Finally, the wind flag for each level is determined by:

1. $SX \geq 1$ or $DX \geq 1$ or $SXX \geq 1$ or $DXX \geq 1$ .... *Flag = 1*
2. $SX > 1$ or $DX > 1$ .... *Flag = 2*
3. $SXX > 1 or DXX > 1$ .... *Flag = 3*
4. $SX > 1$ and $SXX > 1$ .... *Flag = 3*
5. $DX > 1$ and $DXX > 1$ .... *Flag = 3*

The assumption is made that in the majority of cases, a wind in error at a particular level will exceed the shear limits when compared with the standard pressure levels on both sides of the level, hence the requirement for the sum of the counters to be greater than 1.

3.8 Pilot balloon reports

Pilot balloons or PIBALs are measurements of wind speed and direction only, as a function of height and/or pressure, with the tracking done optically. The term radiowind or rawin is used if the tracking is done electronically. This section applies to both types of observations. The routines for checking PIBAL data are a subset of those used for radiosonde data (Section 3.7). Pibals wind observations at standard pressure levels undergo the same checks against climatological limits and checks for vertical wind shear as were described in sections 3.7.1 and 3.7.5.

4 Summary

The operational atmospheric database at FNOC provides quality controlled observations for use by the Navy's atmospheric analysis and prediction systems. Quality control is critically important since erroneous observations may adversely affect the quality of the numerical products, which in turn could potentially impact Fleet operations. The objective quality control of the meteorological observations is performed prior to storage in the database and follows the procedures described in this note.

The objective QC compares the observations against gross error limits and evaluates the internal consistency of the report. Radiosonde and pilot balloon reports also undergo extensive vertical consistency checks. For radiosondes, the vertical consistency checks include tests for unlikely lapse rates, hydrostatic consistency between reported mandatory pressure levels, and consistency between mandatory and significant pressure levels. Both rawinsonde and pilot balloon reports are tested for unrealistic wind speed and directional shears.

The purpose of this report is to provide the details necessary to access and use the quality controlled observations in the operational atmospheric database. The data processing, formats and database structure are discussed in section 2. A description of the quality control procedures follows in section 3. Working with raw observations always presents unforeseen challenges and obstacles. Sometimes, the problems originate prior to arrival of the observations at FNOC. Others are introduced by the data processing at FNOC. Either way, they must be identified and handled prior to use by the operational products. The known problems and corrections (when feasible) for specific observation types are also discussed in section 3.

Appendix A

Tables of Codes

Data type	Record identifier	Format tables
Radiosondes	S0X	B.1,B.2
Pilot balloons	PIB	B.1,B.2
Satellite soundings (thickness)	S0F	B.11,B.12 B.13,B.14
Satellite soundings (temperature)	S0G, S0H	B.11,B.12 B.14,B.15
Satellite cloud-tracked winds	TSX, TWX	B.16,B.17
Marine (synoptic) observations	SHX	B.6,B.7 B.8,B.10
Land (synoptic) observations	SMX	B.6,B.7 B.8
Aviation hourlies (airways)	SAX	B.6,B.7 B.8
METAR (international airways)	MTR	B.6,B.7 B.8,B.9
Aircraft reports	S0A	B.3,B.4 B.5
Reconnaissance aircraft reports	S0B	B.3,B.4 B.5
SSM/I geophysical data records	SS5	B.16,B.17
Australian sea-level pressure bogus	PAB	B.6,B.7
FNOC marine synthetic observations	BOG	B.6,B.7
FNOC tropical cyclone synthetic obs.	GTO	B.1,B.2

Table A.1: Record identifiers and relevant format tables according to observation type.

Code figure	Description
11	Rawindsonde data
12	Pilot wind data
23	Aircraft data
31	Manual or automatic surface land observation
33	Surface observation from fixed ship or buoy
34	Surface observation from mobile ship or drifting buoy
35	Fixed buoy
36	FNOC sea level pressure and wind bogus
37	Australian sea level pressure bogus
38	Coastal marine (C-Man) data
39	Unidentifiable marine data type
41	Satellite sounding data
61	Satellite wind data
91	Experimental satellite sea surface wind speed data
98	Undeterminable data sources

Table A.2: Data Source Index

Code figure	Description
01	Surface level but not standard (pressure or height) level
02	Significant (non-standard pressure level) temperature or humidity
03	Tropopause but not at standard pressure level
04	Significant wind level not at standard (pressure or height) level
05	Maximum wind level not at standard (pressure or height) level
06	Significant temperature or humidity and wind, non-standard (p/H) level
10	Standard (pressure or height) level only
11	Surface level and standard (pressure or height) level
12	Significant temperature or humidity and standard pressure level
13	Tropopause level and standard pressure level
14	Significant wind level and standard (pressure or height) level
15	Maximum wind level and standard (pressure or height) level
16	Significant temperature or humidity and wind, standard (p/H) level

Table A.3: Type of level in upper-air data

Code figure	Description
0	Sea-level pressure
1	Station pressure
6	Geopotential of 850 mb
7	Geopotential of 700 mb
8	Geopotential of 500 mb
9	Unknown

Table A.4: Pressure code indicator

Code figure	Description
1	DMSP/SSMT F-8 for S0G, S0H and SS5
2	DMSP/SSMT F-9 for S0G and S0H
8	NOAA/TIROS/TOVS NOAA-10 for S0G and S0H
9	NOAA/TIROS/TOVS NOAA-11 for S0G and S0H
35	NOAA/TIROS/TOVS NOAA-10 for S0F
36	NOAA/TIROS/TOVS NOAA-11 for S0F
52	DMSP/SSMT F-8 for S0F
53	DMSP/SSMT F-9 for S0F
66	Unspecified geostationary satellite
99	Unknown

Table A.5: Instrument type for satellite derived observations

Code figure	Description
0	Processing technique not specified.
1	Clear path; automated statistical regression.
2	Partly cloudy path; automated statistical regression.
3	Cloudy path; automated statistical regression.
4	Clear path; automated statistical regression; interactive quality control.
5	Partly cloudy path; autoated statistical regression; interactive quality control.
6	Cloudy path; autoated statistical regression; interactive quality control.

Table A.6: Indicator figure for data processing technique used in SATEM code.

Code figure	Description
0	Miscellaneous SATEM information (required record)
1	Layer thickness between a reference pressure level and a standard isobaric surface (SATEM-Parts A and C)
2	Layer precipitable water between a reference pressure level and a standard isobaric surface (SATEM-Part A)
3	Layer mean temperature between a reference pressure level and a standard isobaric surface (SATEM-Parts B and D)

Table A.7: Type of satellite sounding level

IH Code	Description
blank	Value either not checked or found correct
3	Value found erroneous during horizontal control check

IV Code	Description
0	Vertical control check has not been made
1	Value found correct during vertical control check
2	Value found suspect during vertical control check
3	Value found erroneous during vertical control check
4	Observed value found erroneous during vertical control check; reconstituted value inserted
5	Vertical control check made - most likely value entered
6	Original value missing - reconstituted value inserted
7	Original value missing - value assigned
8	Value found erroneous during check against certain limits
9	Original value missing; no control check made

IL Code	Description
0	Checks against certain limits has not been made
1	Value found correct during check against certain limits
2	Value found suspect during check against certain limits
3	Value found erroneous during check against certain limits
4	Observed value found erroneous during check against certain limits; reconstituted value inserted
5	Check against certain limits made - most likely value entered
6	Original value missing - reconstituted value inserted
9	Original value missing; no control check made

Table A.8: Quality-control marks for upper air: horizontal checks (IH), vertical checks (IV) and checks against limits (IL)

Code figure	Description
0	Not checked
1	Observed value found correct during QC check
2	Observed value suspect
3	Observed value erroneous
4	Original value erroneous - substitution inserted (ship position only)
7	Value consistent with present and past observations (ship position only)
8	Value is not consistent with present and past observations (ship position only)
9	Observed value missing, no QC made

Table A.9: Quality-control indicators for surface land and marine reports.

Code figure	Description
0	Not specified
1	Low level of subjective confidence in observation
2	Medium level of subjective confidence in observation
3	High level of subjective confidence in observation

Table A.10: Subjective confidence factor

Code figure	Description
0	Quality control has not been made
1	The report was found correct during quality control
2	Suspect
3	Erroneous

Table A.11: Quality control indicator of satellite reports

Appendix B

Tables of Data Formats

Parameter	Number of characters	Position number	Units	Remarks
Unique report identifier	1	1		Unique character *
Data source index	2	2-3		See Table A.2
Block station number	5	4-8		
Elevation	4	9-12	meters	
Latitude	5	13-17	degrees and hundredths	North (+) South (-)
Longitude	5	18-22	degrees and hundredths	From 0.00 to 359.99
Instrument type	2	23-24		See Table A.5
Year	2	25-26		89 = 1989
Month	2	27-28		01-12 = January-December
Day	2	29-30		01-31
Hour	2	31-32		00-23 UTC
Minutes	2	33-34		00-59
Number of logical records	3	35-37		Variable number

Table B.1: Upper-air data format. Report identification record. Ship identifiers are stored in the 5 characters, left justified and blank filled if necessary. 'SHIP ' indicates that the name was unknown.

Parameter	Number of characters	Position number	Units	Remarks
Type of level	2	1-2		See Table A.3
Pressure	5	3-7	10^{-1} mb	
Height	5	8-12	gpm	
Quality Control: Height	2	13-14		See Table A.8
Temperature	4	15-18	10^{-1} °C	
Quality Control: Temperature	2	19-20		See Table A.8
Dew-point depression	4	21-24	10^{-1} °C	
QC: Dew-point depression	2	25-26		See Table A.8
Wind direction	3	27-29	degrees	
Wind speed	3	30-32	$m s^{-1}$	
Quality Control: Wind	2	33-34		See Table A.8
Record number	3	35-37		Record number within report

Table B.2: Upper-air level data record

Parameter	Number of characters	Position number	Units	Remarks
Report identifier	1	1		Unique character *
Data source index	2	2-3		See Table A.2
Aircraft Identification	6	4-9		First 6 characters of aircraft ID
Type of wind	4	10		0 = doppler; 1 = fix-to-fix; 2 = other
Number of wind reports	2	11-12		
Latitude	5	13-17	degrees and hundredths	North (+) South (-)
Longitude	5	18-22	degrees and hundredths	From 0.00 to 359.99
Optional record indicator	1	23		0 = no;1 = yes
Type of quality check	1	24		0 = no QC check; 1 = horizontal QC done; 2 = QC limits check made
Year	2	25-26		89 = 1989
Month	2	27-28		01-12 = January-December
Day	2	29-30		01-31
Hour	2	31-32		00-23 UTC
Minutes	2	33-34		00-59
Number of logical records	3	35-37		Variable number

Table B.3: Aircraft format. Report identification record. The aircraft name is left-justified with unused characters blank-filled. 'AIRCFT' indicates the name is unknown.

Parameter	Number of characters	Position number	Units	Remarks
Pressure	4	1-4	mb	At flight altitude
Quality Control: Pressure	1	5		See Table A.8
Height	5	6-10	meters	Pressure altitude
Quality Control: Height	1	11		See Table A.8
Temperature	4	12-15	10^{-1} °C	At flight altitude
Quality Control: Temperature	1	16		See Table A.8
Not used	4	17-20		
D-value	5	21-25	meters	
Not used	4	26-34		
Record number	3	35-37		Record number within report

Table B.4: First aircraft data record (mandatory).

Parameter	Number of characters	Position number	Units	Remarks
Type of wind	2	1-2		0 = doppler; 1 = fix-to-fix; 2 = other
Latitude of wind	4	3-6	Degrees and tenths	
Longitude of wind	4	7-10	Degrees and tenths	
Direction of wind	3	11-13	Degrees true	
Speed of wind	3	14-16	$m s^{-1}$	
Quality Control: Wind	1	17		See Table A.8
Not used	17	18-34		
Record number	3	35-37		

Table B.5: Second aircraft data record (mandatory)

Parameter	Number of characters	Position number	Units	Remarks
Unique report identifier	1	1		Unique character *
Data source index	2	2-3		See Table A.2
Block station number	5	4-8		
Elevation	4	9-12	meters	
Latitude	5	13-17	degrees and hundredths	North (+) South (-)
Longitude	5	18-22	degrees and hundredths	From 0.00 to 359.99
Instrument type	2	23-24		See Table A.5
Year	2	25-26		89 = 1989
Month	2	27-28		01-12 = January-December
Day	2	29-30		01-31
Hour	2	31-32		00-23 UTC
Minutes	2	33-34		00-59
Number of logical records	3	35-37		Variable number

Table B.6: *Surface land/marine format.* Report identification record. The names are left-justified and blank filled if necessary. Unknown names are replaced with 'SHIP ' or 'BUOY ' as appropriate.

Parameter	Number of characters	Position number	Units	Remarks
Total cloud amount (N)	2	1-2	oktas	Code table 2700
Wind direction (dd)	3	3-5	degrees true	variable wind given as 990
Wind speed (ff)	3	6-8	$m s^{-1}$	
Quality Control: Wind	1	9		See Table A.9
Horizontal visibility (vv)	2	10-11		Code table 4377
Present weather (ww)	2	12-13		Code table 4677
Past weather (W)	2	14-15		Code table 4500
Pressure code indicator	1	16		See Table A.4
Sea-level or station pressure or geopotential height	5	17-21	10^{-1} mb or gpm	See Pressure Code Indicator
Quality Control: Pressure/height	1	22		See Table A.9
Air temperature	4	23-26	10^{-1} °C	
Quality Control: Air temperature	1	27		See Table A.9
Amount of C_L or C_M clouds (N_h)	2	28-29	oktas	Code table 2700
Clouds of genera Sc, St, Cu, Cb (C_L)	2	30-31		Code table 0513
Height of cloud base (h)	2	32-33		Code table 1600
Clouds of genera Ac, As, Ns (C_M)	2	34-35		Code table 0515
Clouds of genera Ci, Cs, Cc (C_H)	2	36-37		Code table 0509

Table B.7: First surface data record

Parameter	Number of characters	Position number	Units	Remarks
Dew point depression	3	1-3	10^{-1} °C	
QC: Dew point depression	1	4		See Table A.9
Not used	1	5		
Nature of pressure tendency (a)	2	6-7		Code table 0200
Magnitude of pressure tendency(ppp)	3	8-10	10^{-1} mb	
Quality Control: Pressure tendency	1	11		See Table A.9
Not used	26	12-37		

Table B.8: Second surface data record

Parameter	Number of characters	Position number	Units	Remarks
Significant cloud amount (N_s)	2	1-2	Oktas	Code table 2700
Significant cloud type (C)	2	3-4		Code table 0500
Significant cloud height ($h_s h_s$)	2	5-6		Code table 1677
Significant cloud amount (N_s)	2	7-8	Oktas	Code table 2700
Significant cloud type (C)	2	9-10		Code table 0500
Significant cloud height ($h_s h_s$)	2	11-12		Code table 1677
Significant cloud amount (N_s)	2	13-14	Oktas	Code table 2700
Significant cloud type (C)	2	15-16		Code table 0500
Significant cloud height ($h_s h_s$)	2	17-18		Code table 1677
Significant cloud amount (N_s)	2	19-20	Oktas	Code table 2700
Significant cloud type (C)	2	21-22		Code table 0500
Significant cloud height ($h_s h_s$)	2	23-24		Code table 1677
Not used	13	25-37		

Table B.9: Supplementary surface cloud-data record

Parameter	Number of characters	Position number	Units	Remarks
Period of wind waves	2	1-2	seconds	
Height of wind waves	2	3-4	0.5 m	
Direction of swell	2	5-6		Code table 0877
Period of swell	2	7-8	seconds	Code table 3155
Height of swell	2	9-10	0.5 m	
Not used	6	10-16		
Sea surface temperature	4	17-20	10^{-1} °C	
QC: Sea surface temperature	1	21		See Table A.9
Ship's course during past 3 hours	2	22-23		Code table 0700
Ship's average speed during past 3 hours	2	24-25		Code table 4451
Not used	6	26-31		
Quality Control: Ship position	1	32		See Table A.9
Not used	5	33-37		

Table B.10: Additional surface data record for marine report

Parameter	Number of characters	Position number	Units	Remarks
Report indicator	1	1		Unique character *
Data source index	2	2-3		See Table A.2
Not used	5	4-8		
Data processing indicator	2	9-10		See Table A.6
Not used	2	11-12		
Latitude	5	13-17	degrees and hundredths	North (+) South (-)
Longitude	5	18-22	degrees and hundredths	From 0.00 to 359.99
Instrument type	2	23-24		See Table A.5
Year	2	25-26		89 = 1989
Month	2	27-28		01-12 = January-December
Day	2	29-30		01-31
Hour	2	31-32		00-23 UTC
Minutes	2	33-34		00-59
Number of logical records	3	35-37		Variable number

Table B.11: Satellite sounding format. Report identification record.

Parameter	Number of characters	Position number	Units	Remarks
Type of level	2	1-2	Code figure = 0	See Table A.7
Not used	22	3-24		
Number of reported thickness layers	2	25-26		From SATEM Parts A and C
Number of reported precipitable water layers	2	27-28		From SATEM Part A
Number of reported mean temperature layers	2	29-30		From SATEM Parts B and D
Not used	3	31-33		
Quality control flag	1	34		See Table A.11
Logical record number	3	35-37		Record number within report

Table B.12: Miscellaneous satellite sounding data (always second record within satellite sounding observation).

Parameter	Number of characters	Position number	Units	Remarks
Type of level	2	1-2	Code figure = 1	See Table A.7
Objective thickness quality indicator	2	3-4	percent	
Pressure at reference level	5	5-9	10^{-1} mb	base or standard pressure
Standard level pressure	5	10-14	10^{-1} mb	
Layer thickness	4	15-18	tens of gpm	
Objective thickness quality indicator	2	19-20	percent	
Standard level pressure	5	21-25	10^{-1} mb	
Standard level pressure	5	26-30	10^{-1} mb	
Layer thickness	4	31-34	tens of gpm	
Logical record number	3	35-37		Within satellite sounding report

Table B.13: Optional record for satellite sounding thickness data (SATEM Code Parts A and C).

Parameter	Number of characters	Position number	Units	Remarks
Type of level	2	1-2	Code figure = 2	See Table A.7
Index of accuracy for precipitable water	2	3-4	percent	percent of derived value
Pressure at reference level	5	5-9	10^{-1} mb	base or standard pressure
Standard level pressure	5	10-14	10^{-1} mb	
Layer precipitable water	4	15-18	mm	
Index of accuracy for precipitable water	2	19-20	percent	
Standard level pressure	5	21-25	10^{-1} mb	
Standard level pressure	5	26-30	10^{-1} mb	
Layer precipitable water	4	31-34	mm	
Logical record number	3	35-37		Within satellite sounding report

Table B.14: Optional record for satellite sounding precipitable water data (SATEM Code Parts A).

Parameter	Number of characters	Position number	Units	Remarks
Type of level	2	1-2	Code figure = 3	See Table A.7
Objective mean temperature quality indicator	2	3-4	percent	
Pressure at reference level	5	5-9	10^{-1} mb	base or standard pressure
Standard level pressure	5	10-14	10^{-1} mb	
Layer mean temperature	4	15-18	10^{-1} °C	
Objective mean temperature quality indicator	2	19-20	percent	
Standard level pressure	5	21-25	10^{-1} mb	
Standard level pressure	5	26-30	10^{-1} mb	
Layer mean temperature	4	31-34	10^{-1} °C	
Logical record number	3	35-37		Within satellite sounding report

Table B.15: Optional record for satellite sounding temnerature data(SATEM Code Parts A and C).

Parameter	Number of characters	Position number	Units	Remarks
Report indicator	1	1		Unique character *
Data source index	2	2-3		See Table A.2
Data processing method used	2	4-5		Code figure = 05 for SSM/I
Not used	17	6-22		
Instrument type	2	23-24		See Table A.5
Year	2	25-26		89 = 1989
Month	2	27-28		01-12 = January-December
Day	2	29-30		01-31
Hour	2	31-32		00-23 UTC
Minutes	2	33-34		00-59
Number of logical records	3	35-37		Variable number

Table B.16: Satellite cloud tracked winds and SSM/I wind speeds. Report identification record.

Parameter	Number of characters	Position number	Units	Remarks
Latitude	4	1-4	degrees and tenths	North (+) South (-)
Longitude	4	5-8	degrees and tenths	From 0.00 to 359.99
Unused	2	9-10		
Pressure	3	11-13	mb	At effective wind level
Subjective pressure confidence factor	1	14		See Table A.10
Objective QC flag	1	15		See Table A.11
Temperature	3	16-18	10^{-1} °C	
Wind direction	3	19-21	degrees true	
Wind speed	3	22-24	$\mathrm{m\,s^{-1}}$	
Not used	13	25-37		

Table B.17: Record for wind and temperature data

Parameter	Number of characters	Position number	Units	Remarks
Hour	2	1-2		00-23 UTC
Minute	2	3-4		00-59
Latitude	3	5-8	degrees and tenths	North (+) South (-)
Longitude	3	9-12	degrees and tenths	From 0.00 to 359.9
Wind speed	3	13-15		
Quality control: Wind speed	1	16		
Rain rate	2	17-18		
Water vapor over ocean	3	19-21		
Soil moisture	2	22-23		
Liquid water	3	24-26		
Cloud water	3	27-29		
Surface type	1	30		
Rain flag	2	31-32		
Not used	2	33-34		
Record number	3	35-37		Record number within report

Table B.18: Record for SSM/I wind speeds over oceans.

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A new, operational meteorological database has been developed to provide quality controlled observations for the atmospheric analysis and prediction systems at Fleet Numerical Oceanography Center (FNOC). Quality control is a vital and necessary first step in atmospheric analysis and prediction since erroneous observations can adversely impact the accuracy of these environmental products. The meteorological observations are subjected to various validation- and error-checks prior to their storage in the operational atmospheric database. This technical note describes the quality control procedures, database structure and data formats used for the operational atmospheric database. It also discusses the specific details pertaining to the local implementation of the quality control system. These include: the treatment of multiple, non-identical reports from the same station; errors introduced by data processing; and the subjective quality control of marine observations. The same quality control procedures and data formats were used by the Naval Postgraduate School for some of the observations gathered during the Tropical Cyclone Motion experiment (TCM-90).

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